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5G DL Out-Of-Order Delivery

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Abstract

Fifth Generation (5G) networks implement packet re-reordering functionality at the New Radio Packet Data Convergence Protocol (NR-PDCP) layer, mitigating packet transmission issues, but potentially introducing undesirable delays in transmitting downlink packets to an access point. By introducing logistics to manage packet reordering, the transmission delays are reduced. For example, metadata is added to transmitted packets to assist the network stack at the access point in processing packets received out of order, allowing the packets to be provided to the stack relatively quickly.

Background

For Fifth Generation (5G) wireless communications, packets can be received at a node, such as at user equipment (UE), out of order relative to an intended order of the packets. Accordingly, 5G standards require a packet re-ordering function to be implemented at the New Radio Packet Data Convergence Protocol (NR-PDCP) layer. Because packet reordering is implemented at this layer, a Radio Link Control (RLC) downlink (DL) service data unit (SDU) will be delivered to the PDCP layer, even when there is a gap, or hole, in the received packets. In addition, to allow the network stack of a network access point (AP) to receive retransmitted packets, 5G standards require implementation of a PDCP reordering timer wherein, upon expiration of the timer, DL packets are delivered to the AP even if there are missing packets before the delivered packets in the intended packet order (See, e.g., U.S. Patent Pub. No. 20180317236A1, U.S. Patent Pub. No. 20180098241A1).

These mechanisms mitigate, to some extent, DL packet transmission issues resulting from packet drop in the wireless link to the access point. However, the PDCP reordering timer is configured for each network cell and is fixed relative to variable factors, such as the distance

between the UE and the corresponding base station, as well as the traffic congestion status of the base station. Thus, even when a packet is successfully received at the baseband processor, the PDCP reordering timer can introduce an undesirable delay for transmitting downlink packets to the AP.

Description

As described herein, even when either the RLC layer or PDCP layer is agnostic of the traffic transferring over the bearer, logistics are introduced on top of the layer to allow the baseband (BB) processor to make better decisions with respect to reordering packets. The logistics allow packets to be provided to an AP network stack relatively quickly, and without triggering network responses that can impact packet throughput, such as triggering Transmission Control Protocol (TCP) selective acknowledgement (SACK) conditions.

The BB processor implements different logistics for Universal Data Protocol (UDP) and TCP packets, as follows:

UDP:

For UDP packets, the BB processor identifies the packet type (i.e., that the packet is a UDP packet) and delivers the UDP packet once the packet is received at the PDCP layer, without delay. Accordingly, the DNS-RSP packet is quickly sent to the AP network stack in order to initiate the corresponding session immediately, while other out-of-order DL packets are delivered to the AP under the assumption that the receiving application can handle ordering. This assumption is likely valid, because packet ordering frequently occurs beyond the base station in the network.

TCP:

For TCP packets, in some cases the BB processor receives multiple TCP streams transferred over one Data Radio Bearer. Accordingly, some of the multiple TCP streams may experience out-of-order packet reception, while others receive packets in order. The BB processor is typically unaware of whether packets are being received out of order, as the BB processor is typically unable to examine the packets (and such examination is sometimes impossible due to packet encryption).

Accordingly, for TCP DL packets, or any other DL packets that the BB processor is not able to recognize, the BB processor delivers the packets to the AP Network Stack immediately regardless of the state PDCP reordering timer. The BB processor adds metadata to the packet to assist processing by the network stack when the packets are received out of order. By including this metadata, described further below, the network stack processes out of order packets without triggering a TCP SACK condition, which in turn impacts the TCP congestion window (TCP CWND) from the sender and potentially downgrades the packet throughput.

The following metadata is transmitted, with each DL packet descriptor, to the AP to assist the network stack's processing:

DRB (Data-Radio-Bearer) ID: Identifies the data bearer that the internet traffic is associated with**.**

Retransmission Time (unit: ms): Indicates how long the retransmission could take for the wireless link.

In-Seq/Out-of-Seq Flag: Indicates whether the packet is in-sequence or out-of-sequence delivery for the wireless link

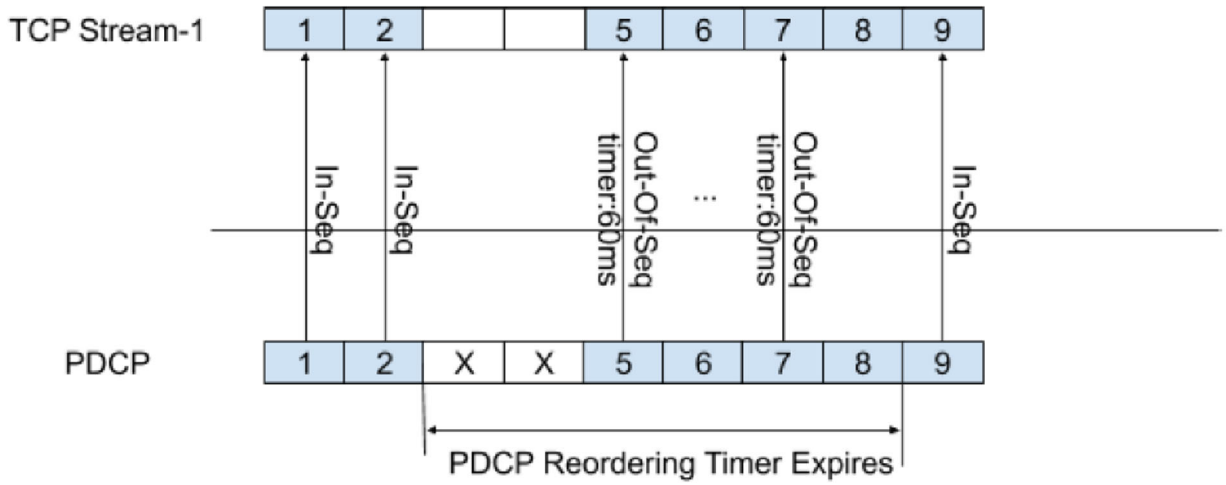
The retransmission time is predicted based on how long it takes for the RLC missing packets to be retransmitted from the base station, allowing the network stack to decide the timing of triggering a TCP SACK condition if there are any DL packets missing. The retransmission time is calculated according to the following formula:

$$T_{retrans} = a * T_{latest\_retrans} + (1 - a) * T_{retrans}$$

where $T_{latest\_retrans}$ is the most recent time for a missing DL-RLC SDU to be received through network RLC retransmission, and where a is configurable modem parameter, and is set to 0.3 by default. In addition, if the $T_{retrans}$ value is higher than the PDCP reordering time set by the network, the $T_{retrans}$ value is set to the PDCP reordering time.

The In-Seq/Out-of-Seq Flag is implemented in the NR-PDCP layer. Based on the PDCP sequence number, the BB processor indicates whether the DL packets were received in-sequence or out-of-sequence. This flag is useful in the case where there are missing packets in one TCP stream while there are no dropped packets for the wireless link. The flag allows a TCP-SACK condition to be triggered quickly when there is no expectation that the missing packet will be retransmitted. In response to expiration of the PDCP Re-ordering timer, the In-Sequence Flag is set for all the DL packets in front of the NR-PDCP RX_DELIV packet to ensure that network performance is maintained.

An example of the In-Seq/Out-of-Seq Flag being set for packets in a TCP stream is illustrated below:



The benefits of adding the metadata include quick delivery of UDP and DNS-RSP packets. For multiple TCP streams, downlink throughput is improved because dropped packets in one TCP stream do not delay provision of packets in other TCP streams. In addition, the approach described herein can be applied to both 5G and to LTE networks. For LTE networks, the 3GPP Rel15 specification introduced rlc-OutOfOrderDelivery-r15. By setting the BB processor to behave as if RLC-OutOf-Order Delivery was configured by the network, and by triggering the packet delivery from LTE-RLC to NR-RLC immediately, the techniques described herein are implemented in an LTE network.